QUANTUM MECHANICS

What You Need to Know to Start Learning Physics and Think Like Physicists

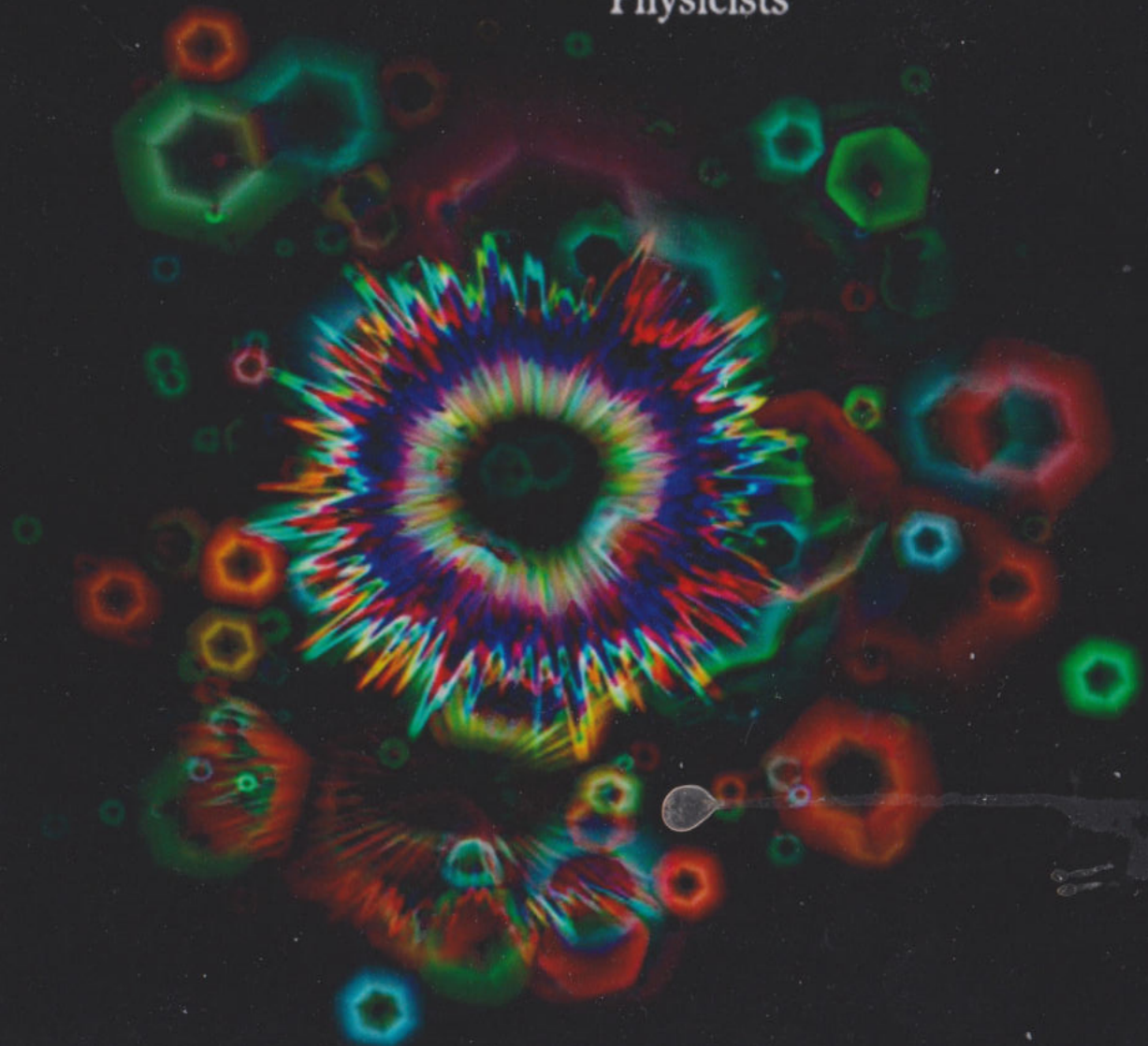

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TABLE OF CONTENTS

CHAPTER 1 1

1. Brief History of Disciplines 1

CHAPTER 2 9

2. Basic Principles 9

2.1 State Function 9

2.2 Microsystem 12

2.3 Bohr Theory 14

2.4 Pauli's Principles 15

CHAPTER 3 18

3. Historical Background 18

3.1 Blackbody Radiation Problem 18

3.2 Photoelectric Effect Experiment 19

3.3 Atomic Spectroscopy 20

3.4 Light Quantum Theory 21

3.5 Bohr's Quantum Theory 22

3.6 De Broglie Wave 22

CHAPTER 4 25

4. Experimental Phenomena 25

4.1 Photoelectric Effect 25

4.2 Atomic Energy Level Transitions 26

4.3 Volatility of Electrons 27

CHAPTER 5 30

5. Related Concepts 30
5.1 Waves and Particles 30
5.2 Measurement Process 32
5.3 Uncertainty 33
5.4 Quantum Entanglement 35
5.5 Quantum Decoherence 36
CHAPTER 6 39
6. Evolution of Theory 39
6.1 Emergence and Development of Theory 39
6.2 Boundaries from Classical Physics 44
6.3 Combination with Special Relativity 46
6.4 Strong-Weak Interaction 47
6.5 Gravity 47
CHAPTER 7 49
7. Applied Disciplines 49
7.1 Atomic Physics 50
7.2 Nuclear Physics 52
7.3 Solid State Physics 52
7.4 Quantum Informatics 53
CHAPTER 8 54
8. Quantum Mechanics Explanation 54
8.1 Quantum Mechanics Problems 54
8.2 Explanation 55
Conclusion 61
Appendix 62

Is the Performance of Quantum Mechanics Overturned? 62
What is the Randomness of Quantum Mechanics? 62
What did Yale 's Thesis Say? 65
God Still Rolls the Dice 68
Index 70

CHAPTER 1

1. Brief History of Disciplines

Quantum mechanics is a theory that describes microscopic matter. It is considered together with relativity as the two basic pillars of modern physics. Many physical theories and sciences such as atomic physics, solid physics, nuclear physics and particle physics, and other related Disciplines are all based on quantum mechanics.

Quantum mechanics is a physical theory describing atomic and subatomic scales. This theory was formed in the early 20th century and completely changed people's understanding of the composition of matter. In the micro world, particles are not billiards, but buzzing jumping probability clouds. They do not exist in only one position, nor do they reach point B through a single path from point A. According to quantum theory, particles often behave like waves, and the wave function used to describe particle behavior predicts possible characteristics of a particle, such as its position and

velocity, rather than certain characteristics. Some weird concepts in physics, such as the principle of entanglement and uncertainty are derived from quantum mechanics.

At the end of the 19th century, the deficiencies of classical mechanics and classical electrodynamics in describing microscopic systems became more and more obvious. Quantum mechanics was developed by Max Planck, Niels Bohr, Werner Heisenberg, Erwin Schrödinger, Wolfgang Pauli, Louis De Broglie and Max in the early 20th century. Born, Enrico Fermi, Paul Dirac, Albert Einstein, Compton and many other physicists co-founded.

The development of quantum mechanics revolutionized people's understanding of the structure of matter and its interactions. Quantum mechanics was able to explain many phenomena and predict new, unimaginable phenomena that were later proved by very precise experiments. Except for the gravitational force described by general relativity, all other basic physical interactions can be described within the framework of quantum mechanics (quantum field theory).

Quantum mechanics does not support free will, but there are uncertainties such as the probability wave in matter in the micro world, but it still has a stable objective law, does not use human will as a transfer and denies fatalism. First, there is still an insurmountable distance between this kind of randomness on the micro-scale and the macro-scale in the usual sense. Secondly, it is difficult to prove whether this randomness is irreducible and things are combined by their independent evolution. There is a dialectical relationship between diversity as a whole, contingency and necessity. Whether there is randomness in nature is still an open question. What determines this gap is Planck's constant. Many examples of random events in statistics are strictly decisive.

In quantum mechanics, the state of a physical system is represented by a wave function, and any linear superposition of wave functions still represents a possible state of the system. Corresponds to the effect of the operator representing this quantity on its wave function; the modulus square of the wave function

represents the probability density of the physical quantity as its variable.

Quantum mechanics was developed on the basis of old quantum theory. Old quantum theory includes Planck 's quantum hypothesis, Einstein 's light quantum theory and Bohr 's atomic theory.

In 1900, Planck proposed the radiation quantum hypothesis. It is assumed that the exchange of energy between electromagnetic fields and matter is realized in a discontinuous form (energy quantum). The size of the energy quantum is proportional to the radiation frequency. The Planck formula is given and the black body radiant energy distribution is given correctly.

In 1905, Einstein introduced the concept of photon and gave the relationship between the energy and momentum of photon, the frequency and wavelength of radiation and successfully explained the photoelectric effect. Later, he also proposed that the vibrational energy of solids is also quantized, thereby explaining the specific heat problem of solids at low temperatures.

In 1913, Bohr established the quantum theory of atoms on the basis of Rutherford's original nuclear atom model. According to this theory, the electrons in an atom can only move in discrete orbits. When moving in orbits, the electrons neither absorb energy nor emit energy. Atoms have certain energy. This state is called steady state and the atom, in order to absorb or radiate energy, it is necessary to move from one state to another. Although this theory has many successes, there are still many difficulties for further explanation of experimental phenomena.

After people realized that light has the duality of waves and particles, in order to explain some phenomena that cannot be explained by classical theory, French physicist De Broglie proposed the concept of matter waves in 1923. It is believed that all microscopic particles are accompanied by a wave, which is the so-called De Broglie wave.

De Broglie's material wave equation: $E = \hbar\omega$, $p = h/\lambda$, among them $\hbar = h/2\pi$ can be made by $E = p2/2m$ get $\lambda = h/\sqrt{2mE}$

Because micro particles have wave-particle duality, the laws of motion followed by micro particles are different from those of macro objects and the quantum mechanics that describe the laws of micro particles are different from the classic mechanics that describe the laws of macro objects. When the size of a particle transitions from micro to macro, the rules it follows also transition from quantum mechanics to classical mechanics.

In 1925, Heisenberg based on the physical theory of only observing the cognition of observables, abandoned the concept of unobservable orbits and proceeded from the observable radiation frequency and intensity and established matrix mechanics with Born and Jordan. In 1926, Schrodinger was based on quantum.

The understanding of the volatility of the observation system found the equations of motion of the microscopic system and established the wave dynamics. The mathematical equivalence of wave dynamics and matrix mechanics was also proved shortly thereafter; Dirac and Jordan developed independently. This paper presents a universal transformation theory and gives a concise and

complete mathematical expression of quantum mechanics.

When a microparticle is in a certain state, its mechanical quantities (such as coordinates, momentum, angular momentum, energy, etc.) generally do not have a definite value but have a series of possible values and each possible value appears with a certain probability. When the state of the particle is determined, the probability that the mechanical quantity has a certain possible value is also completely determined. This is the uncertainty relationship obtained by Heisenberg in 1927. At the same time, Bohr proposed the principle of union and gave a further explanation of quantum mechanics.

The combination of quantum mechanics and special theory of relativity has produced relativity quantum mechanics. Quantum electrodynamics was developed through the work of Dirac, Heisenberg and Pauli and others. After the 1930s, a quantization theory describing various particle fields, the quantum field theory, was formed, which formed the theoretical basis for describing basic particle phenomena.

Heisenberg also proposed the uncertainty principle, which is expressed as follows: $\Delta x \Delta p \geq h/4\pi$

CHAPTER 2

2. Basic Principles

The basic mathematical framework of quantum mechanics is based on the description and statistical interpretation of quantum states, the equations of motion, the correspondence rules between observed physical quantities, the measurement postulate, and the identical particle postulate.

2.1 State Function

The state of the physical system is represented by a state function and any linear superposition of the state function still represents a possible state of the system. The change of state over time follows a linear differential equation that predicts the behavior of the system. Physical quantities are represented by operators that meet certain conditions and represent certain operations. Operations that measure a certain physical quantity of a physical system in a certain state correspond to the effect of the operator representing the

quantity on its state function. The possible value of the measurement is determined by the eigen equation of the operator and the expected value of the measurement is calculated by an integral equation containing the operator. In general, quantum mechanics does not predict a single result definitively for an observation. Instead, it predicts a set of different outcomes that can occur and tells us the probability of each outcome occurring.

In other words, if we make the same measurement on a large number of similar systems and each system starts in the same way, we will find the measurement result is that A appears a certain number of times; B appears a different number of times and so on. One can predict the result as an approximation of the number of occurrences of A or B but cannot predict the specific results of individual measurements. The modular square of a state function represents the probability of a physical quantity as its variable. Based on these basic principles and other necessary assumptions, quantum mechanics can explain various phenomena of atoms and subatoms.

According to the Dirac symbol, the state function is represented by <Ψ | and | Ψ>, the probability density of the state function is represented by ρ = <Ψ | Ψ>, and its probability flow density is represented by (? / 2mi) (Ψ * ▽ Ψ− Ψ ▽ Ψ *) indicates that the probability is the spatial integral of the probability density.

The state function can be expressed as a state vector expanded in an orthogonal space set such as $|\Psi\rangle = \sum C_i |i\rangle$ Where | i> is the space basis vectors orthogonal to each other, $\langle m|n\rangle = \delta_{m,n}$ is a Dirac function that satisfies the orthogonal normalization property. State function satisfies Schrödinger wave equation, $i\hbar(\partial/\partial t)|m\rangle = \hat{H}|m\rangle$. After separating the variables, you can get the evolution equation in the invisible time state $\hat{H}|m\rangle = E_n|m\rangle$, En is the energy eigen value, and H is the Hamiltonian.

So the quantization of classical physical quantities comes down to the solution of Schrödinger's wave equation.

$$i\hbar\frac{\partial}{\partial t}\Psi(r,t) = \hat{H}\Psi(r,t)$$

2.2 Microsystem

- System Status

In quantum mechanics, there are two changes in the state of the system. One is that the state of the system evolves according to the equation of motion, which is a reversible change; the other is the measurement of irreversible changes that change the state of the system. Therefore, quantum mechanics cannot give a definite prediction of the physical quantity that determines the state but only the probability of the value of the physical quantity. In this sense, the causal laws of classical physics have failed in the microsphere.

Based on this, some physicists and philosophers assert that quantum mechanics abandons causality, while other physicists and philosophers believe that the causality law of quantum mechanics reflects a new type of causality—probability causality. In quantum mechanics, the wave function representing a quantum state is defined in the entire space and any change in the state is realized in the entire space at the same time.

- Micro System

Since the 1970s, experiments on the correlation of distant particles have shown that space-like separation events are related to quantum mechanical predictions. This association contradicts the theory of special relativity that objects can only transfer physical interactions at a speed not greater than the speed of light. Therefore, some physicists and philosophers, in order to explain the existence of this connection, have proposed that there is a global causality or global causality in the quantum world. This kind of local causality, which is based on special relativity, can be derived from Decide the behavior of related systems as a whole.

Quantum mechanics uses the concept of quantum states to characterize the state of microscopic systems, which has deepened people's understanding of physical reality. The nature of micro-systems is always manifested in their interaction with other systems, especially observational instruments.

When people described the observation results in the language of classical physics, they found that under

different conditions, the microscopic system was mainly manifested as wavy images or mainly behaved as particles. The concept of a quantum state expresses the possibility of microwaves and particles interacting with the instrument to appear as waves or particles.

2.3 Bohr Theory

Bohr, an outstanding contributor to quantum mechanics, states: Electronic orbit quantization concept. Bohr believes that the nucleus has a certain energy level. When the atom absorbs energy; the atom transitions to a higher energy level or excited state. When the atom emits energy, the atom transitions to a lower energy level or ground state. According to this theory, the Rydberg constant can be calculated from the theory, which is in good agreement with the experiment.

However, Bohr's theory also has limitations. For larger atoms, the calculation results are very inaccurate. Bohr still retains the concept of orbits in the macro world. In fact, the coordinates of electrons in space are uncertain and electrons are more concentrated. It means that the probability of electrons appearing here is greater;

otherwise, the probability is smaller. Many electrons come together and can be called an electron cloud.

2.4 Pauli's Principles

In Pauli's principle, the state of a quantum physical system cannot be completely determined, so the distinction between particles with identical characteristics (such as mass, charge, etc.) in quantum mechanics has lost its significance. In classical mechanics, the position and momentum of each particle are all fully known and their trajectories can be predicted. With one measurement, each particle can be identified. In quantum mechanics, the position and momentum of each particle is expressed by a wave function. Therefore, when the wave functions of several particles overlap each other, the practice of "tagging each particle" loses its meaning.

The indistinguishability of this identical particle has profound effects on the symmetry of the state and the statistical mechanics of the multi-particle system. For example, in the state of a multi-particle system composed of identical particles, when exchanging two

particles 1 and 2, we can prove that they are not symmetrical or antisymmetric. Particles in a symmetrical state are called bosons and particles in an antisymmetric state are called fermions. In addition, the spin exchange also forms symmetry. Particles with half of the spins (such as electrons, protons and neutrons) are antisymmetric, so they are fermions. Particles with integer spins (such as photons) are symmetrical, so It's a boson.

The relationship between the spin, symmetry and statistics of this esoteric particle can only be derived through the theory of relativity quantum field and it also affects the phenomena in non-relativity quantum mechanics. One consequence of Fermion's antisymmetry is the Pauli Exclusion Principle, that is, two Fermions cannot occupy the same state. This principle has great practical significance. It means that in our material world consisting of atoms, electrons cannot occupy the same state at the same time, so after the lowest state is occupied, the next electron must occupy the next lowest state until all states are satisfied. This phenomenon

determines the physical and chemical properties of the substance.

The thermal distributions of fermions and boson states are also very different. Bosons follow Bose-Einstein statistics and fermions follow Fermi-Dirac statistics.

CHAPTER 3

3. Historical Background

From the end of the 19th century to the beginning of the 20th century, classical physics has reached a point of perfection but it has encountered some serious difficulties in experiments. These difficulties are regarded as "a few dark clouds in the clear sky." Here are a few difficulties:

3.1 Blackbody Radiation Problem

At the end of the 19th century, many physicists were very interested in blackbody radiation.

The black body is an idealized object. It can absorb all the radiation that hits it and convert them into thermal radiation. The spectral characteristics of this thermal radiation are only related to the temperature of the black body. This relationship cannot be explained using classical physics. By treating atoms in objects as tiny harmonic oscillators, Max Planck was able to obtain a Planck formula for black body radiation. But when

leading this formula, he had to assume that the energies of these atomic harmonic oscillators were not continuous (which is contrary to the viewpoint of classical physics), but discrete: En = nhν

Here n is an integer and h is a natural constant. (Later the formula proved to be correct, n should be replaced by n + 1/2, see the zero-point energy). In 1900, Planck was very careful when describing his radiant energy protonation. He only assumed that the radiant energy absorbed and emitted was quantized. Today, this new natural constant is called Planck's constant in honor of Planck's contribution. Its value: $h = 6.626176.10^{-34}$.

3.2 Photoelectric Effect Experiment

Due to ultraviolet radiation, a large amount of electrons escape from the metal surface. The research found that the photoelectric effect has the following characteristics:

a. There is a certain critical frequency; only when the frequency of the incident light is greater than the critical frequency will photoelectrons escape.

b. The energy of each photoelectron is only related to the frequency of the irradiated light.

c. When the frequency of the incident light is higher than the critical frequency, as long as the light hits it, the photoelectron is observed almost immediately.

For the above three characteristics, c is a quantitative problem, while a and b cannot be explained by classical physics in principle.

3.3 Atomic Spectroscopy

Spectral analysis has accumulated a wealth of data and many scientists have sorted and analyzed them and found that the atomic spectrum is a discrete linear spectrum rather than a continuous distribution. There is also a very simple rule for the wavelength of the spectral line.

After the discovery of the Rutherford model, according to classical electrodynamics, charged particles that move at an accelerated rate will continue to radiate and lose energy. Therefore, the electrons moving around the nucleus will eventually fall into the nucleus due to a large

loss of energy; then the atom collapses. The real world shows that atoms are stable.

Energy Sharing Theorem

The energy sharing theorem does not apply at very low temperatures.

3.4 Light Quantum Theory

Quantum theory first broke through on the issue of blackbody radiation. In order to deduce his formula theoretically, Planck proposed the quantum concept –h but it did not attract much attention at the time. Einstein used the quantum hypothesis to propose the concept of light quantum, thereby solving the problem of photoelectric effect. Einstein further applied the concept of energy discontinuity to the vibration of atoms in solids, successfully solving the phenomenon that the specific heat of solids tended to be o when T → oK. The concept of light quantum has been directly verified in Compton scattering experiments.

3.5 Bohr's Quantum Theory

Bohr creatively used the concept of Planck-Einstein to solve the problems of atomic structure and atomic spectrum and proposed his quantum theory of atoms. It mainly includes two aspects:

a. Atomic energy can only exist stably in a series of states corresponding to discrete energies. These states become stationary.

b. When an atom transitions between two stationary states, the frequency v of absorption or emission is unique, given by hv = En-Em.

Bohr's theory has achieved great success, opening the door to people's understanding of the structure of the atom for the first time but as people deepen their understanding of the atom, its problems and limitations have gradually been discovered.

3.6 De Broglie Wave

Inspired by Planck and Einstein's light quantum theory and Bohr's atomic quantum theory, considering that light has wave-particle duality, De Broglie imagined that

physical particles also have wave-particle dual images based on the principle of analogy. He proposed this hypothesis, on the one hand, he tried to unify physical particles with light and on the other hand, to understand the discontinuity of energy more naturally, in order to overcome the shortcomings of artificial nature of the Bohr quantization condition. The direct proof of the fluctuation of real particles was realized in the electron diffraction experiment in 1927.

Quantum mechanics itself was established over a period of 1923-1927. Two equivalent theories, matrix mechanics and wave dynamics, are proposed almost simultaneously. The introduction of matrix mechanics is closely related to Bohr's early quantum theory. On the one hand, Heisenberg inherited the rational cores of early quantum theory, such as the concepts of energy quantization, steady state and transition, while abandoning some concepts without experimental basis, such as the concept of electronic orbits. The matrix mechanics of Heisenberg, Born and Jordain are physically measurable and each physical quantity is given a matrix. Their algebraic

operation rules are different from classical physical quantities and obey algebra that is not easy to multiply.

Wave dynamics originate from the idea of material waves. Inspired by matter waves, Schrodinger found a motion equation of matter in a quantum system, the Schrodinger equation, which is the core of wave dynamics. Later, Schrödinger also proved that matrix mechanics is completely equivalent to wave dynamics, which are two different forms of expression of the same mechanical law. In fact, quantum theory can be expressed more generally, which is the work of Dirac and Jordan.

The establishment of quantum physics is the crystallization of the joint efforts of many physicists and it marks the first collective victory of physics research.

CHAPTER 4

4. Experimental Phenomena

4.1 Photoelectric Effect

In 1905, Albert Einstein extended Planck's quantum theory and proposed that not only the interaction between matter and electromagnetic radiation is quantized but that quantization is a theory of basic physical properties. With this new theory, he was able to explain the photoelectric effect. Experiments by Heinrich Rudolf Hertz and Philip Leonard found that electrons can be ejected from metals through light. At the same time, they can measure the kinetic energy of these electrons.

Regardless of the intensity of the incident light, only when the frequency of the light exceeds a threshold value (cut-off frequency) will no electrons be emitted. The kinetic energy of the electrons that are ejected thereafter increases linearly with the frequency of the light and the intensity of the light only determines the number of emitted electrons. Einstein came up with the theory of

the quantum of light to explain this phenomenon. The quantum energy of light is hv.

In the photoelectric effect, this energy is used to eject electrons from the metal (work function) and accelerated electrons (kinetic energy).

Einstein's photoelectric effect equation: $1/2mv^2 = hv - wo$

4.2 Atomic Energy Level Transitions

The Rutherford model in the early 20th century was an atomic model that was considered correct at the time. This model assumes that negatively charged electrons, like planets orbiting the sun, orbit positively charged nuclei. Coulomb and centrifugal forces must be balanced during this process. There are two problems with this model that cannot be solved. First, according to classical electromagnetics , this model is unstable. According to electromagnetics, an electron is constantly being accelerated during its operation and at the same time it should lose its energy by emitting electromagnetic waves, so that it will soon fall into the nucleus . Secondly, the emission spectrum of the atom is composed of a series of discrete emission lines. For example, the

emission spectrum of the hydrogen atom is composed of an ultraviolet series (Ryman series), a visible series (Balmer series) and other infrared series. According to the classical theory, the emission spectrum of atoms should be continuous.

In 1913, Niels Bohr proposed the Bohr model named after him. This model is the atomic structure and spectral lines and gives a theoretical principle. Bohr believes that electrons can only move in orbits with a certain energy En. By absorbing photons of the same frequency, one can jump from a low-energy orbit to a high-energy orbit.

The Bohr model can explain hydrogen atoms, the improved Bohr model and can also explain ions with only one electron, namely He +, Li2 +, Be3 +, etc. But it cannot accurately explain the physical phenomena of other atoms.

4.3 Volatility of Electrons

De Broglie hypothesized that electrons are also accompanied by a wave, and he predicted that electrons should produce an observable diffraction phenomenon when they pass through a small hole or crystal. In 1925,

when Davidson and Ge Mo were conducting electron scattering experiments in nickel crystals, they first obtained the electron diffraction phenomenon in crystals. After learning about De Broglie's work, the experiment was carried out more accurately in 1927. The experimental results are in full agreement with De Broglie's formula, which strongly proves the electron's volatility.

The fluctuation of electrons is also reflected in the interference phenomenon of electrons when passing through double slits. If only one electron is emitted at a time, it will randomly excite a small bright spot on the photosensitive screen after passing through the double slit in the form of a wave. Emitting a single electron multiple times or emitting multiple electrons at a time, interference fringes between light and dark will appear on the photosensitive screen. This again proves the volatility of electrons.

The position of the electrons on the screen has a certain distribution probability and the fringe image unique to the double slit diffraction can be seen with time. If a light

slit is closed, the image formed is the distribution probability of the wave unique to the single slit.

It is never possible to have half an electron. In this electron double-slit interference experiment, it is an electron that passes through two slits at the same time in the form of a wave. It has interfered with itself. It is worth emphasizing that the superposition of wave functions here is the superposition of probability amplitudes rather than the probability superposition as in the classic example. This "state superposition principle" is a basic assumption of quantum mechanics.

CHAPTER 5

5. Related Concepts

5.1 Waves and Particles

The granularity of matter is characterized by energy E and momentum p, and the characteristics of waves are expressed by the frequency γ and its wavelength λ of the electromagnetic wave. The scale factor of these two physical quantities is determined by the Planck constant h (h = 6.626 * 10 ^ (-34) J · s) contacted.

E = hγ, E = mc ^ 2 simultaneously, we get: m = hγ / c ^ 2 (this is the relativistic mass of the photon. Since the photon cannot be stationary, the photon has no static mass) and p = mv. Then p = vhγ / c ^ {2} (p is momentum)

Partial differential wave equation of one-dimensional plane wave of particle wave, its general form for dξ / dx = (1 / γ) (dξ / dt).

The classical wave equation of a plane particle wave propagating in three-dimensional space is $d\xi / dx + d\xi / dy + d\xi / dz = (1 / \gamma) (d\xi / dt)$.

The wave equation is a description of the volatility of microscopic particles using the wave theory in classical mechanics. Through this bridge, the wave-particle duality in quantum mechanics is well expressed.

The u in equation of the classical wave equation implies the discontinuous quantum relationship $E = h\gamma$ and De Broglie relationship $\lambda = h / p$. Multiplying the right side of $v\lambda$ by a factor (h / h) with Planck constant h, we get

$u = (\gamma h) \quad (\lambda / h)$

$= E / p$

The equal relationship $u = E / p$ makes the connection between classical physics and quantum physics continuous and discontinuous (local) and unified.

De Broglie relation $\lambda = h / p$ and quantum relation $E = h\gamma$ (and Schrödinger equation). These two relations actually represent the unified relationship between volatility and particle nature. De Broglie matter waves are wave-

particle integration. Waves of real matter particles, photons, electrons, etc.

Heisenberg Uncertainty Principle

That is the uncertainty of the object's momentum multiplied by the reduced Planck's constant of which is greater than or equal to 1/2.

5.2 Measurement Process

One of the main differences between quantum mechanics and classical mechanics lies in the place of measurement process in theory. In classical mechanics, the position and momentum of a physical system can be determined and predicted with infinite precision. At least in theory, the measurement has no effect on the system itself and can be performed with infinite precision. In quantum mechanics, the measurement process itself affects the system.

To describe the measurement of an observable quantity, the state of a system needs to be linearly decomposed into a linear combination of a set of eigenstates of the observable quantity. The measurement process can be

regarded as a projection on these eigenstates and the measurement result is the eigenvalue corresponding to the eigenstate being projected. If for each infinite copy of this system, each copy is measured once, we can obtain the probability distribution of all possible measured values. The probability of each value is equal to the absolute square of the coefficient of the corresponding eigenstate.

It can be seen that the measurement order of two different physical quantities A and B may directly affect their measurement results. In fact, this is the case with incompatible observables.

5.3 Uncertainty

The most well-known incompatible observables are the position x and the momentum p of a particle. The product of their uncertainties Δx and Δp is greater than or equal to half Planck's constant.

The "Uncertainty Principle" discovered by Heisenberg in 1927, also often referred to as "Uncertainty Relationship", refers to the mechanical quantities (such as coordinates and momentum) represented by two misaligned

operators; Time, energy, etc.). It is not possible to have definite measured values at the same time. The more accurate one is, the less accurate the other is. It shows that because the measurement process interferes with the behavior of microscopic particles, the measurement sequence is not interchangeable, which is a basic law of microscopic phenomena.

In fact, physical quantities such as the coordinates and momentum of particles are not information that already exists and are waiting for us to measure. Measurement is not a simple reflection process but a transformation process. Their measured values depend on our measurement methods. It is the mutual exclusion of the measurement methods that leads to the uncertainty relationship.

By decomposing a state into a linear combination of observable eigenstates, the probability amplitude c i of the state at each eigenstate can be obtained. The absolute square of the probability amplitude | c i | 2 is the probability that the eigenvalue n i is measured, which is also the probability that the system is in the

eigenstate. ci can be calculated by projecting onto the eigenstates.

Therefore, the same measurement of an observable quantity of an identical system of the same system generally yields different results; unless the system is already in the eigenstate of the observable quantity. By performing the same measurement on each system in the ensemble in the same state, a statistical distribution of measured values ni can be obtained. All experiments are faced with this measurement and the statistical calculation of quantum mechanics.

5.4 Quantum Entanglement

Often the state of a system composed of multiple particles cannot be separated into the state of a single particle composed of them. In this case, the state of a single particle is called entangled. Entangled particles have amazing properties that go against common intuition. For example, the measurement of a particle can cause the wave packet of the entire system to collapse immediately, so it also affects another distant particle entangled with the particle being measured. This

phenomenon does not violate the special theory of relativity, because at the level of quantum mechanics, you cannot define particles before measuring them. In fact, they are still a whole. However, after measuring them, they will leave the state of quantum entanglement.

5.5 Quantum Decoherence

As a basic theory, quantum mechanics should, in principle, be applicable to physical systems of any size, that is, not only limited to microscopic systems, then it should provide a method for transitioning to macroscopic classical physics. The existence of quantum phenomena raises a question, namely how to explain the classic phenomena of macroscopic systems from the viewpoint of quantum mechanics. What can't be seen directly is how the superposition state in quantum mechanics can be applied to the macro world.

In 1954, in a letter to Max Bonn, Einstein raised the question of how to explain the positioning of macroscopic objects from the perspective of quantum mechanics. He pointed out that the phenomenon of quantum mechanics is too small to explain this problem.

Another example of this problem is by the Schrödinger proposed the Schrödinger's cat thought experiment.

It was not until about 1970 that people began to truly understand that the above mentioned thought experiments were actually not practical because they ignored the inevitable interaction with the surrounding environment. It turns out that the superimposed state is very susceptible to the surrounding environment. For example, in a double-slit experiment, the collision or emission of electrons or photons with air molecules can affect the phase relationship between the states that are critical to the formation of diffraction.

In quantum mechanics, this phenomenon is called quantum decoherence. It is caused by the interaction of the state of the system with the effects of the surrounding environment. This interaction can be expressed as the entanglement of each system state with the state of the environment.

The result is that superposition is only effective when considering the entire system (i.e., experimental system + environmental system) and if only the system state of

the experimental system is considered in isolation, then only the classic distribution of the system is left. Quantum decoherence is the main way to explain the classical properties of macroscopic quantum systems in quantum mechanics today.

Quantum decoherence is the biggest obstacle to the realization of quantum computers. In a quantum computer, multiple quantum states need to remain superimposed for as long as possible. Short decoherence time is a very big technical problem.

CHAPTER 6

6. Evolution of Theory

6.1 Emergence and Development of Theory

Quantum mechanics is a physical science that describes the structure, movement and changes of the microscopic world of matter. It is a major leap in the development of human civilization in the 20th century. The discovery of quantum mechanics has triggered a series of epoch-making scientific discoveries and technological inventions and has made important contributions to the progress of human society.

At the end of the 19th century, when major achievements were made in classical physics, a series of phenomena that could not be explained by classical theory were discovered one after another. Thermal radiation theorem found by German physicist Wien through the measurement of thermal radiation spectrum. In order to explain the thermal radiation spectrum, the German physicist Planck proposed a bold hypothesis: during the generation and absorption of thermal radiation, the

energy is exchanged one by one with hf as the smallest unit.

This hypothesis of quantization of energy not only emphasizes the discontinuity of thermal radiation energy but also contradicts the basic concept of "radiation energy has nothing to do with frequency and is determined by amplitude" and cannot be included in any classical category. Only a few scientists at the time seriously studied the issue.

Einstein proposed the quantum theory of light in 1905. In 1914, American physicist Millikan published the results of the photoelectric effect experiment, which verified Einstein's photon quantum theory.

In 1913, the Danish physicist Bohr proposed a steady state in order to solve the instability of the Rutherford atomic planetary model (according to classical theory, the electrons in an atom, make a circular motion around the nucleus to radiate energy, causing the orbital radius to shrink until it falls into the nucleus). Assumption: The electrons in the atom do not operate in orbits of any classical mechanics like planets. The amount of

stabilizing orbit fpdq must be an integer multiple of h (the angular momentum is quantized), that is, fpdq = nh, n is called quantum Number. Bohr also proposed that the process of atomic emission is not classical radiation but a discontinuous transition process of electrons between different stable orbital states.

The frequency of light is determined by the energy difference between orbital states. In this way, Bohr's atomic theory explained the discrete spectral lines of hydrogen atoms with its simple and clear images and intuitively explained the periodic table of chemical elements in the electronic orbital state, which led to the discovery of element 72 thorium. This year triggered a series of major scientific advances. This is unprecedented in the history of physics.

Due to the deep connotation of quantum theory, the Copenhagen school represented by Bohr has conducted in-depth research on this. They have studied the correspondence principle, matrix mechanics, incompatible principle, uncertainty relationship and complementary principle. Probabilistic interpretations of quantum mechanics have contributed.

In April 1923, the American physicist Compton published the phenomenon of frequency reduction caused by X-rays scattered by electrons, namely the Compton effect. According to classical wave theory, the scattering of waves by stationary objects does not change the frequency. According to Einstein Light Quantum, this is the result of the collision of two particles. The photon quantum not only transfers energy but also momentum to the electrons during the collision, which makes the photon quantum theory experimentally proved.

Light is not just an electromagnetic wave, it is also a particle with energy momentum. In 1924, the American Austrian physicist Pauli published the "incompatible principle": two electrons in an atom cannot be in the same quantum state at the same time. This principle explains the shell structure of the electrons in the atom.

This principle is applicable to all basic particles of solid matter (commonly called fermions, such as protons, neutrons, quarks, etc.) and constitutes the basic point of quantum statistical mechanics- Fermi statistics. In order to explain the fine structure of the spectral lines and the anomalous Zeeman effect, Pauli suggested that for the

original orbital state of the electron, in addition to the existing three quantum numbers corresponding to the classical mechanical quantities (energy, angular momentum and its components, a fourth quantum number should be introduced. This quantum number was later called spin and is a physical quantity that describes an intrinsic property of elementary particles.

In 1924, French physicist de Broglie proposed expression of duality wave-particle Einstein de Broglie relation: E = hV, p = h / in, the physical characterization of particles of energy. Momentum is equal to the frequency and wavelength that characterize wave properties through a constant h.

In 1925, German physicists Heisenberg and Bohr established the first mathematical description of quantum theory-matrix mechanics. In 1926, Austrian scientists proposed a partial differential equation describing Schrödinger's equation for the continuous space-time evolution of matter waves and gave another mathematical description of quantum theory, wave dynamics. In 1948, Feynman founded the path integral form of quantum mechanics.

Quantum mechanics has universally applicable significance in the range of high speed and microscopic phenomena. It is one of the foundations of modern physics. It has important theories in the development of surface physics, semiconductor physics, condensed matter physics, particle physics, low temperature superconducting physics, quantum chemistry and molecular biology in modern science and technology. The emergence and development of quantum mechanics marks a major leap in human understanding of nature from the macro world to the micro world.

6.2 Boundaries from Classical Physics

In 1923, Niels Bohr put forward the corresponding principle, thinking that the quantum system (especially the number of particles) reached a certain limit if the quantum system can be accurately described by classical theory. The background of this principle is that, in fact, many macroscopic systems can be described very accurately by classical theories such as classical mechanics and electromagnetics. Therefore, it is generally believed that in very large systems, the characteristics of quantum mechanics will gradually

degrade to the characteristics of classical physics and the two do not conflict. Therefore, the correspondence principle is an important auxiliary tool for building an effective quantum mechanical model.

The mathematical basis of quantum mechanics is very extensive. It only requires that the state space is Hilbert space and its observables are linear operators. However, it does not specify which Hilbert space and which operators should be selected in practice. Therefore, in practical situations, the corresponding Hilbert space and operator must be selected to describe a particular quantum system. Correspondence principle is an important auxiliary tool to make this choice. This principle requires the predictions made by quantum mechanics to gradually approximate the predictions of classical theory in larger systems. The limits of this large system are called classic limits or corresponding limits.

Therefore, heuristics can be used to build a model of quantum mechanics and the limit of this model is the corresponding model of classical physics.

6.3 Combination with Special Relativity

In the early days of quantum mechanics, special relativity was not taken into account. For example, when using the harmonic oscillator model in particular, the use of a non-relativistic of the harmonic oscillator. In the early days, physicists tried to link quantum mechanics with special relativity, including replacing the Schrödinger equation with the corresponding Klein-Gordon equation or Dirac equation.

Although, these equations have been very successful in describing many phenomena, they still have defects; especially they cannot describe the generation and destruction of particles in the state of relativity. Through the development of quantum field theory, a true theory of relativity has been produced. Quantum field theory not only quantifies observable quantities such as energy or momentum but also quantizes the fields where media interact. The first complete quantum field theory is quantum electrodynamics, which can completely describe electromagnetic interactions.

Generally, when describing electromagnetic systems, a complete quantum field theory is not needed. A simpler

model is to treat charged particles as a quantum mechanical object in a classical electromagnetic field. This method has been used since the beginning of quantum mechanics. For example, the electronic state of a hydrogen atom can be calculated approximately using the classical 1 / r voltage field. However, when quantum fluctuations in the electromagnetic field play an important role, (for example, a charged particle emits a photon) this approximation method fails.

6.4 Strong-Weak Interaction

Strong interaction of quantum field theory is QCD, the theory described particles consisting of nuclei. Weak interactions and electromagnetic interactions are combined in electrical weak interactions.

6.5 Gravity

So far, gravity alone cannot be used to describe quantum mechanics. Therefore, near black holes or looking at the entire universe as a whole, quantum mechanics may have encountered its applicable boundaries. Neither quantum mechanics nor general relativity can explain the physical state of a particle when it reaches the singularity of a

black hole. General relativity predicts that the particle will be compressed to infinite density; quantum mechanics predicts that because the position of the particle cannot be determined, it cannot reach infinite density and can escape from a black hole.

Therefore, the two most important new physical theories of the 20th century, quantum mechanics and general relativity, contradict each other. Finding the answer to this contradiction is an important goal of theoretical physics (quantum gravity). But so far, it is obviously very difficult to find the quantum theory of gravity. Although, some subclassical approximation theories have been achieved, such as the prediction of Hawking radiation but so far, a whole theory of quantum gravity cannot be found. Studies in this area include string theory.

CHAPTER 7

7. Applied Disciplines

The effects of quantum physics have played an important role in many modern technological equipment. Medical image display devices from lasers, electron microscopes, atomic clocks and nuclear magnetic resonance all rely on the principles and effects of quantum mechanics. The study of semiconductors led to the invention of diodes and transistors and finally paved the way for the modern electronics industry. The concept of quantum mechanics also played a key role in the invention of nuclear weapons.

In these inventions, the concepts and mathematical descriptions of quantum mechanics often rarely directly play a role but the concepts and rules of solid physics , chemistry, materials science or nuclear physics play a major role in all. In these disciplines, quantum mechanics is the foundation. The basic theories of these disciplines are all based on quantum mechanics. The following can only list some of the most significant

applications of quantum mechanics and these listed examples are certainly very incomplete.

7.1 Atomic Physics

Atomic Physics and Chemistry

The chemical properties of any substance are determined by the electronic structure of its atoms and molecules. By analyzing the multi-particle Schrödinger equation including all relevant nuclei and electrons, the electronic structure of the atom or molecule can be calculated. In practice, it is recognized that it is too complicated to calculate such an equation and in many cases, as long as simplified models and rules are used, it is sufficient to determine the chemical properties of a substance. In building such a simplified model, quantum mechanics plays a very important role.

A very common model in chemistry is the atomic orbital. In this model, the multi-particle states of the molecules' electrons are formed by adding together the single-electron states of each atom. This model contains many different approximations (such as ignoring the repulsive forces between electrons, the separation of electron

motion from the nucleus motion, etc.), which can describe the energy levels of atoms approximately and accurately. In addition to the relatively simple calculation process, this model can also intuitively give an image description of the electronic arrangement and orbit.

Through atomic orbits, one can use very simple principles (Hund 's Rule) to distinguish electron arrangements. The rules of chemical stability (eight-law law, magic number) are also easily deduced from this quantum mechanical model.

By adding several atomic orbitals together, this model can be extended to molecular orbitals. Since molecules are generally not spherically symmetric, this calculation is much more complicated than atomic orbitals. A branch of theoretical chemistry, quantum chemistry and computer chemistry, a discipline that specifically uses approximate Schrödinger equations to calculate the structure of complex molecules and their chemical properties.

7.2 Nuclear Physics

Nuclear physics is a branch of physics that studies the properties of the nucleus. It has three major areas: studying the relationship between various types of subatomic particles and their classification, analyzing the structure of atomic nuclei, and driving the corresponding nuclear technology development.

7.3 Solid State Physics

Why is diamond hard, brittle and transparent, while graphite, also made of carbon, is soft and opaque? Why is metal thermally and electrically conductive with metallic luster? How do light-emitting diodes, diodes and transistors work? Why is iron ferromagnetic? What is the principle of superconductivity?

The above examples can make people imagine the variety of solid state physics. In fact, condensed matter physics is the largest branch of physics and all phenomena in condensed matter physics can only be correctly interpreted from a microscopic perspective through quantum mechanics. Using classical physics, at most,

only part of the explanation can be put forward from the surface and phenomenon.

7.4 Quantum Informatics

The focus of research lies on a reliable method for dealing with quantum states. Due to the nature of quantum states that can be superimposed. In theory, quantum computers can operate in parallel. It can be applied in cryptography. In theory, quantum cryptography can produce theoretically absolutely secure cryptography. Another current research project is quantum teleportation using quantum entangled states to teleportation.

CHAPTER 8

8. Quantum Mechanics Explanation

8.1 Quantum Mechanics Problems

In terms of dynamics, the equation of motion of quantum mechanics is that when the state of a system at a certain moment is known, it can predict its state in the future and at any moment in the past according to the equation of motion.

The predictions of quantum mechanics are different from the predictions of classical physics equations of motion (particle motion equations and wave equations). In classical physics theory, the measurement of a system does not change its state; it has only one change and evolves according to the equation of motion. Therefore, the equations of motion can make certain predictions about the mechanical quantities that determine the state of the system.

Quantum mechanics can be regarded as one of the most rigorous physical theories that have been tested. So far,

all experimental data cannot overturn quantum mechanics. Most physicists believe that it almost correctly describes the physical properties of energy and matter in all cases. Nonetheless, there are still conceptual weaknesses and flaws in quantum mechanics. In addition to the lack of the above-mentioned quantum theory of gravity, the interpretation of quantum mechanics has so far been controversial.

8.2 Explanation

If the mathematical model of quantum mechanics and the complete description of physical phenomena within its scope of application, we find that the significance of the probability of each measurement result during the measurement process is different from the probability and meaning of classical statistical theory. Even measurements from the exact same system will be random.

This is different from the probability results in classical statistical mechanics. In classical statistical mechanics, the measurement results are different because the experimenter cannot fully replicate a system, not because

the measurement instrument cannot accurately measure. In the standard interpretation of quantum mechanics, the randomness of measurement is fundamental, which is obtained from the theoretical basis of quantum mechanics.

Although quantum mechanics cannot describe the results of a single experiment, it is still a complete and natural description, which makes people have to draw the following conclusion: there is no objective system characteristic that can be obtained through a single measurement in the world.

The objective characteristics of a quantum mechanical state can only be obtained by describing the statistical distributions reflected in its entire set of experiments. Einstein ("incomplete quantum mechanics", "God does not roll the dice") and Niels Bohr were the first to debate this issue. Bohr maintains the principle of uncertainty and complementarity. In years of intense discussion, Einstein had to accept the uncertainty principle, while Bohr weakened his complementary principle, which ultimately led to today's interpretation of Copenhagen.

Today, most physicists accept the insight that quantum mechanics describes all the known properties of a system and that the measurement process cannot be improved, not because of our technical problems. One consequence of this interpretation is that the measurement process disturbs the Schrodinger equation, causing the system to collapse to its eigenstate. In addition to the Copenhagen interpretation, some other interpretations have been proposed.

1. David Bohm proposed a non-local theory with hidden variables (hidden variable theory). In this interpretation, the wave function is understood as a gravitational wave of a particle. In terms of results, the experimental results of this theoretical prediction are exactly the same as those of the non- relativistic Copenhagen interpretation. Therefore, these two interpretations cannot be distinguished by experimental means. Although, the predictions of this theory are decisive, the exact state of hidden variables cannot be inferred due to the uncertainty principle. The result is the same as the Copenhagen interpretation. Using this to explain the experimental results is also a probabilistic one. So far, it

is uncertain whether this explanation can be extended to relativistic quantum mechanics. Luis De Broglie and others have proposed similar interpretations of hidden coefficients.

2. The multi-world interpretation proposed by Hugh Everett III believes that all the possible predictions made by quantum theory are realized at the same time and these realities become parallel universes that are generally unrelated to each other. In this interpretation, the total wave function does not collapse and its development is decisive. But since we as observers cannot exist in all parallel universes at the same time, we only observe the measurements in our universe, while in other universes we observe the measurements in their universe value. This interpretation does not require special treatment of the measurement. The Schrödinger equation described in this theory is also the sum of all parallel universes.

3. The principle of microscopic action, microscopic forces exist between microscopic particles (microscopic forces can evolve into both macromechanics and micromechanics) and microeffects are behind quantum

mechanics. In deeper theory, the reason why micro-particles exhibit volatility is an indirect objective reflection of micro-forces. Under the principle of micro-actions, the difficulties and confusions faced by quantum mechanics are understood and explained.

4. Another interpretation direction is to change classical logic into quantum logic to eliminate the difficulty of interpretation.

The following are the most important experiments and thought experiments on the interpretation of quantum mechanics:

1. The Einstein-Podowski-Rosen paradox and the related Bell inequality clearly show that quantum mechanical theory cannot be explained by local hidden variables; the possibility of non-local hidden coefficients is not ruled out.

2. The double-slit experiment is a very important quantum mechanics experiment. From this experiment, you can also see the measurement problems of quantum mechanics and the difficulty of interpretation. This is the

simplest and most obvious experiment that shows the duality of waves and particles.

3. Schrödinger's cat

Conclusion

Since quantum technology is aimed at the second information revolution, its future applications will determine its value and it should not be contaminated by the popularity of publishing top journals. Even if this is favored for a while, it will soon be buried in history.

Appendix

Is the Performance of Quantum Mechanics Overturned?

A news report entitled "Schrödinger's cat was finally rescued, and Nature research observed the first quantum transition process" swipes the screen. Title parties such as "Yale's experiment overthrows the randomness of quantum mechanics", "Einstein got it right again" and so on have appeared, as if the invincible quantum mechanics overturned the ditch overnight, many young people lamented that fatalism was back. But is this really the case? Let's take a closer look.

What is the Randomness of Quantum Mechanics?

According to the summary of the master of mathematics and mathematics, Feng Neumann, there are two basic processes in quantum mechanics, one is to evolve deterministically according to Schrödinger's equation and the other is to randomly collapse the quantum superposition state due to measurement. Schrödinger's

equation is the core equation of quantum mechanics. It is deterministic and it has nothing to do with followability. Then the randomness of quantum mechanics comes only from the latter, that is, from the measurement.

This randomness of measurement is what makes Einstein most incomprehensible. He used the metaphor "God won't roll the dice" to oppose the measurement of randomness and Schrödinger also imagined measuring the superposition of life and death of a cat.

But countless experiments have confirmed that to directly measure a quantum superposition state, the result is randomly on one of the eigenstates (probability is the modulus square of the coefficient of each eigenstate in the superposition state), which is the most important thing in quantum mechanics. In order to solve this problem, multiple interpretations of quantum mechanics were born. Among them, the three mainstream interpretations are Copenhagen interpretation, multi-world interpretation and consistent historical interpretation.

The Copenhagen interpretation believes that measurement will cause the quantum state to collapse, that is, the quantum state is instantly destroyed and randomly falls to an eigenstate. The multi-world interpretation feels that the Copenhagen interpretation is too mysterious, so it makes a more mysterious, thinking that every time measurement is a division of the world. The results of all eigenstates exist but they are completely independent (orthogonal) from each other and they cannot interfere with each other. We are only randomly in a certain world. The consistent historical interpretation introduces a quantum decoherence process. Solve the problem from superposition state to classical probability distribution. But in choosing which classic probability, it still returns to the debate on Copenhagen interpretation and multi-world interpretation.

From a logical point of view, the combination of multi-world interpretation and consistent historical interpretation seems to be the most perfect for explaining the measurement problem. Multiple worlds form a total superposition state, that is, the certainty of

the "God perspective" is retained and the single world is retained. However, physics is based on experimental science. These interpretations predict the same physical results and cannot be falsified with each other, so the physical meaning is equivalent, hence the academic circle still mainly adopts the Copenhagen interpretation, that is, collapse. The word stands for measuring the randomness of a quantum state.

What did Yale 's Thesis Say?

This Nature paper from Yale University first paves up a knowledge of quantum mechanics, that is, the quantum transition is a deterministic process in which the quantum superposition state evolves completely according to the Schrödinger equation, that is, the probability amplitude on the ground state | G> is continuously transferred to the excitation according to the Schrodinger equation State | E>, and then transferred back continuously to form an oscillation (frequency is called Rabbi frequency), which belongs to the first type of process summarized by Von Neumann.

This paper measures such a deterministic quantum transition, so it is no surprise to get deterministic results. The selling point of the article is how to prevent this measurement from destroying the original superposition state, or how to prevent the quantum transition from stopping due to sudden measurement. This is not a mysterious technology but a weak measurement method currently widely used in the field of quantum information.

This experiment uses a three-level system artificially constructed by a superconducting circuit. The signal-to-noise ratio is much worse than the actual atomic energy level.

The weak measurement technique used in the experiment is to divide the number of particles in the original ground state | G> (this experiment uses superconducting current) and let it form a superposition state with | D>, while | G> the rest. The number of particles continues to be superimposed with | B>. These two superimposed states are (almost) independent and (almost) do not affect each other.

For example, by controlling the intensity of the two transitional rabies frequencies with light (microwave), the probability amplitude can be close to 1 when | B> is close to 1, and | D> is also close to 1. At this time, when the superposition state of | G> and | B> is measured, it will be found that the number of particles collapses on | B>. At this time, although the superposed states of | G> and | D> have not collapsed, we can know that the probability amplitudes are all above | D>, and then measure the superposed states of | G> and | D>. As a result, the number of particles collapses in | D> Up.

So measuring the superposed state of | G> and | B> itself is a measurement that causes random collapse but this measurement does not cause the superposed state to collapse for the superposed state of | G> and | D> (only very weak Changes) and at the same time can monitor the evolution of the superposition states of | G> and | D>, which has become a weak measurement of the relative state of | G> and | D>.

If this three-level system has only one particle, then when the number of particles collapsed on | B> is 1, the number of particles collapsed on | D> and | G> is zero.

But this three-level system is artificially prepared with superconducting current, which is equivalent to having many electrons available. After some electrons collapse on | B>, there are still some electrons in the superposition of | D> and | G>. Therefore, the multi-particle system also guarantees that this weak measurement experiment can be performed. This is very similar to the cold atom experiment, that is, a large number of atoms have the same energy level system and the probability of the superposition state can be reflected in the relative number of atoms.

God Still Rolls the Dice

To summarize in a sentence, in this nature paper, experimental techniques are used to weakly measure a deterministic process and to actively avoid the measurement of this process that can lead to random results. Everything conforms to the predictions of quantum mechanics and the measurement of quantum mechanics is random. Sex has no effect. So Einstein didn't turn over, God still rolls the dice.

This nature paper just once again verified the correctness of quantum mechanics. Why did it cause such a big misunderstanding? I have to talk about it here. This has nothing to do with the wrong targets that the authors set in the abstract and introduction. It is estimated to make big news. They found the instantaneous idea of the quantum transition proposed by Bohr in 1913 as a target but this idea was proposed as early as 1925 by the Heisenberg equation and Schrodinger equation in 1926 (that is, the formal establishment of quantum mechanics) Was later denied and they also stated clearly in the paper that experiments actually verified Schrödinger's view that transitions are continuously determined evolution. Poor's move was probably to create an effect that was opposed to Einstein, to continue the century debate and to get more attention. But on the question of quantum transition, it was Bohr's earliest idea that was wrong. Heisenberg and Schrödinger were right. It didn't matter what Einstein did.

Index

A

atomic emission 41
atomic model 26
Atomic Physics .4, 50

B

blackbody radiation ..18, 21
Bohr model..... 27

C

classical physics 12, 13, 18, 20, 31, 36, 39, 45, 52, 54
cryptography..... 53

D

Dirac symbol..... 11

E

eigenstate 33, 34, 35, 57, 63, 64
electromagnetic fields..... 4
electromagnetic radiation 25
electrons ..5, 14, 16, 19, 20, 25, 26, 27, 28, 32, 37, 40, 42, 50, 68

H

heuristics 45

I

incident light.... 19, 20, 25

L

light quantum theory..... 4

M

matrix mechanics ..6, 23, 24, 41, 43

N

nuclear atom model..... 5
Nuclear Physics4, 51

O

orbits....5, 6, 14, 23, 27, 40, 51

P

Pauli Exclusion Principle 16
photoelectric effect .4, 19, 21, 25, 26, 40
photon4, 30, 40, 42, 47

Q

Quantum field theory..... 46
Quantum mechanics.. 1, 2, 3, 4, 13, 23, 44, 54
quantum theory. 1, 4, 5, 22, 23, 24, 25, 40, 41, 42, 43, 48, 55, 58

R

radiation frequency.... 4, 6
radiation quantum 4
relativity quantum mechanics. 7, 16

S

Solid State Physics 4, 52

T

theoretical physics 48

U

uncertainty principle... 8, 56, 57

W

wave function. 1, 3, 12, 15, 57, 58
wavelength ... 4, 20, 30, 43

ABOUT THE BOOK

This book discusses important quantum mechanics topics, ranging from theoretical to experimental models of the atom. It is written to help readers understand that the emergence and development of quantum mechanics marks a major change in human understanding of nature.

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